



ENERGY for the FUTURE

CSLF Perspectives for CO₂ EOR as CCUS Offshore

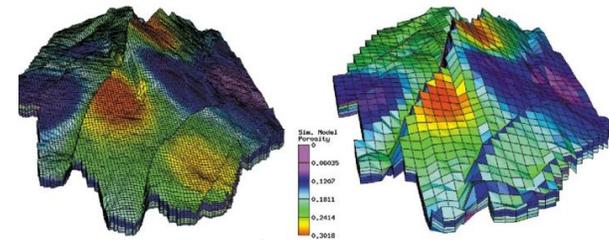
Prof. Arne Graue

Department of Physics and Technology, University of Bergen, Norway

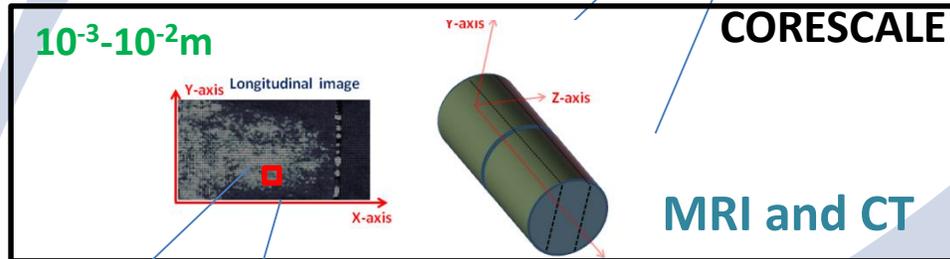
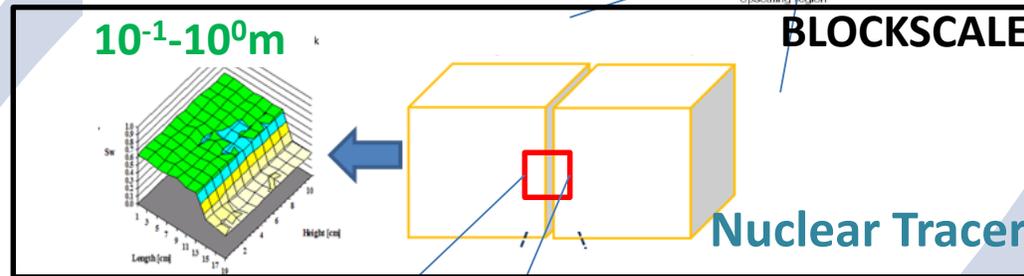
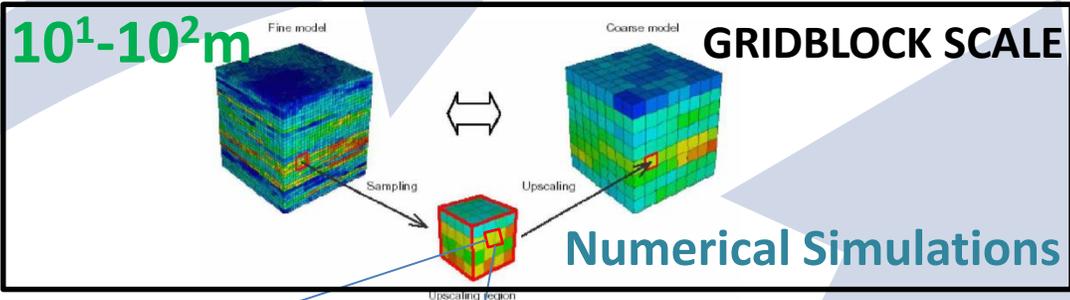
Interdisciplinary CCUS Workshop, U. of Houston, TX, USA, Sept.23-24th, 2019

Length Scales

10^3-10^4m



Petroleum Geo-Services Homepage
www.pgs.com



Imaging techniques

Next Generation CO₂ Flooding

- Main challenges in CO₂ EOR:
 - Early CO₂ breakthrough and poor sweep efficiency
 - Up-scaling laboratory EOR to field performance
- US White Paper:
 - Mobility control in CO₂ EOR, USDOE/Advanced Resource International Inc.
 - Target: 137 Billion bbl
- US import of foreign oil may be reduced by 30%
- "Next generation CO₂ EOR technology" based on mobility control
- 68 billion barrels of oil: 1,35 billion bbl of oil every year for 50 years
- Similar results in the North Sea; pilot in the Snorre Field
- Economic at oil price of US\$ 85 and CO₂ price of US\$ 40/ton
- Need more CO₂
- Carbon Capture Utilization and Storage (CCUS) a win-win situation

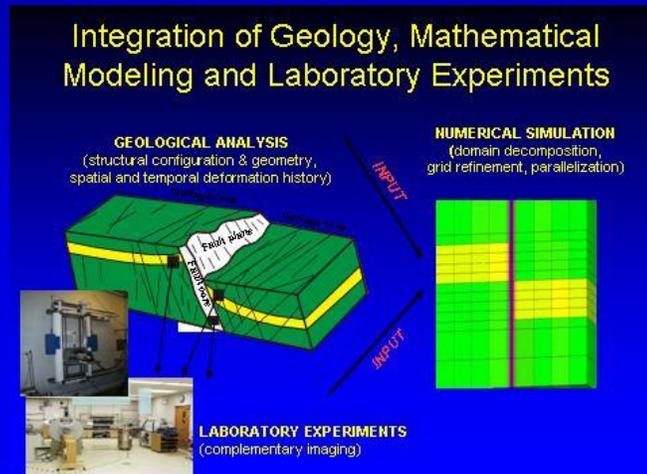
CO₂ EOR Enables CCUS: Integrated EOR (IEOR) for CO₂ Sequestration

CO₂ Foam EOR Mobility Control in Field Pilots in Texas

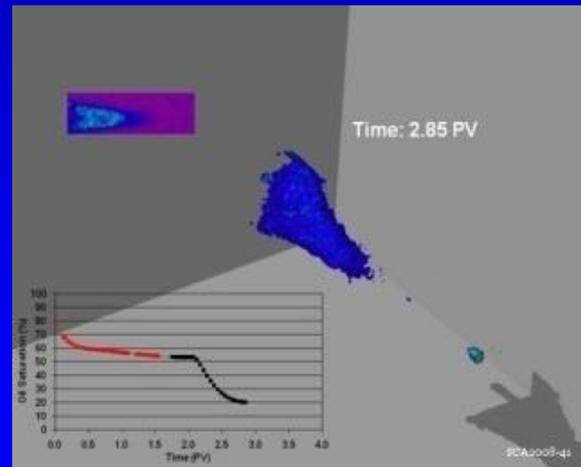
Collaboration: 11 Universities in France, The Netherlands, UK, USA and Norway

Coordinator: Arne Graue, Dept. of Physics, University of Bergen, NORWAY

Funding: CLIMIT Program at the Research Council of Norway and 7 oil companies



Lab to pilot field test



MRI of CO₂ injection



Complementary NTI & MRI facilities



Lab to Field: CO₂ Foam EOR Field Pilots

1981 1987 2014

OBJECTIVE

Cost-effective “Roadmap for Success” for CO₂ EOR implementation on Norwegian Continental Shelf through onshore field trials in Texas

WHY TEXAS?

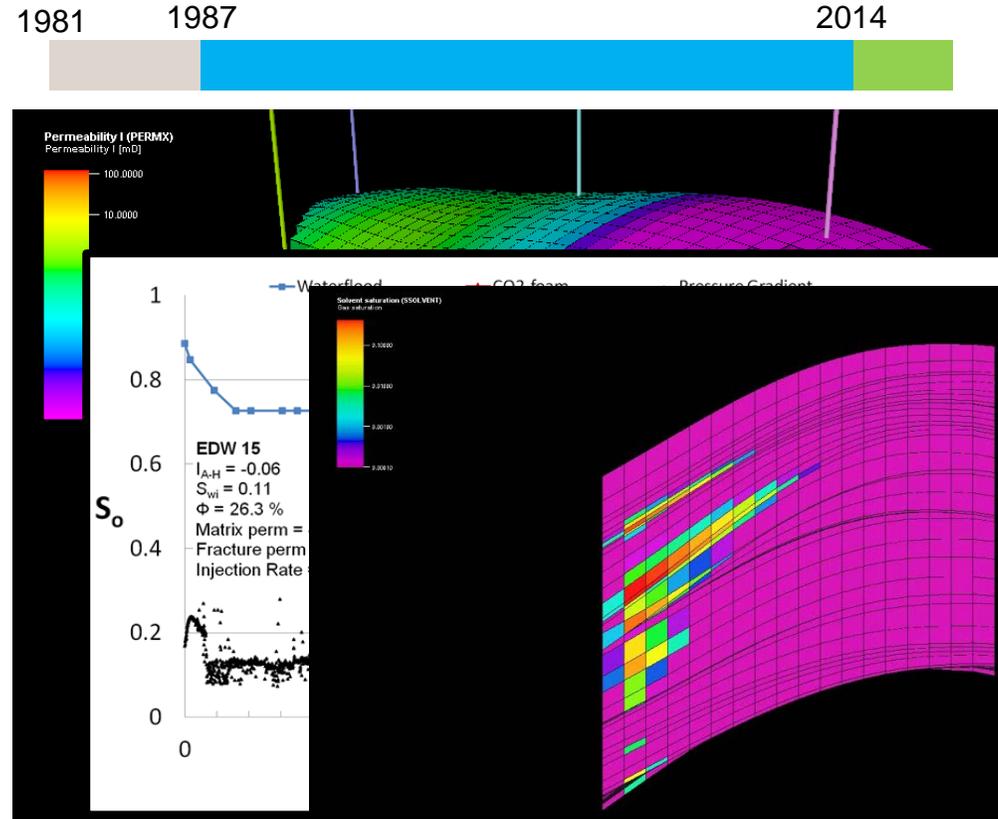
- CO₂ is commercially available; w/infrastructure
- Up-scaling; major challenge in oil recovery
- Fraction of costs of off-shore field tests
- Fast results: short inter-well distances
- 30 years experience in Texas on CO₂ EOR

COLLABORATORS

U. of Bergen	Total	Stanford U.
U. of Bordeaux	Rice U.	National IOR centre
U. of Houston	TU Delft	Schlumberger
Statoil	UT Austin	Shell

FUNDING 15MNOK

Norwegian Research Council, CLIMIT program
Oil Industry (Shell, Total, Schlumberger, Statoil)
+ local independent operators



Laboratory Results

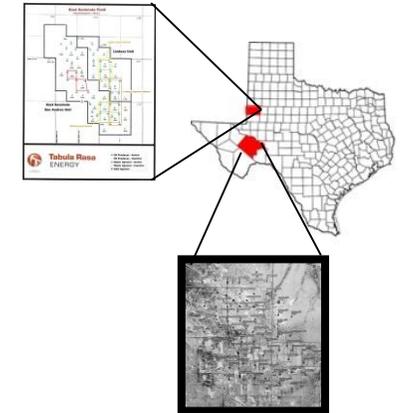
MORE Oil produced:
CO₂ Foam EOR produces 10-30% additional oil after waterflooding

FASTER Production
Operational times reduced up to 90%.

Laboratory Team

Sunniva Fredriksen (PhD)
Arthur Uno Rognmo (PhD)
Michael Jian (PhD)
Connie Wergeland (MSc)
Anders Frøland (MSc)
Andreas G. Polden (MSc)

East Seminole Well Location Map



Ft. Stockton Well Location Map

Simulation Results

EFFICIENT Oil Production:
CO₂ Foam EOR increase sweep efficiency

MORE CO₂ stored:
Displace water to increase CO₂ storage volume

Simulation Team

Zachary Alcorn (PhD)
Mohan Sharma (PhD)
Lars Petter Grønvhig (MSc)
Anna Bang (MSc)
Max Castro (MSc)
Stine Kristiansen (MSc)

CO₂ Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

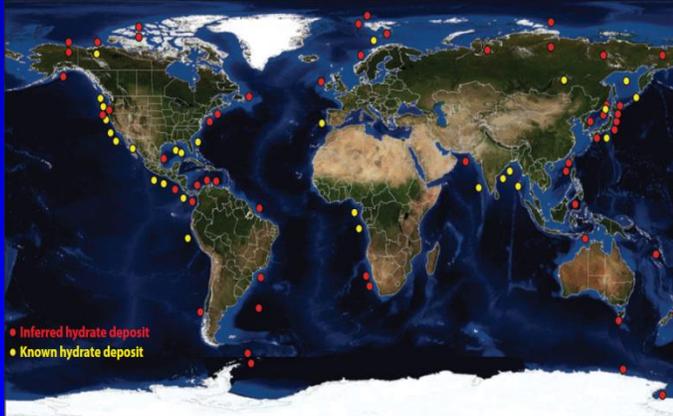
Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY
Funding: ConocoPhillips, Statoil and The Research Council of Norway



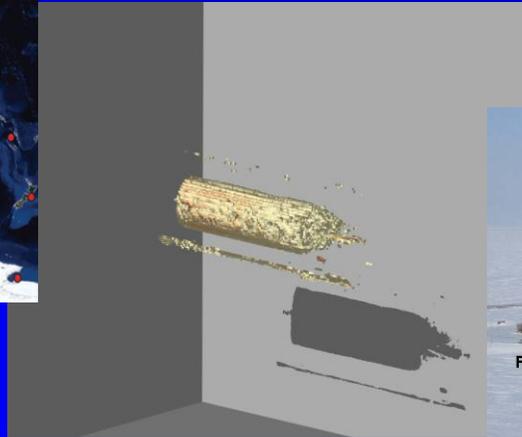
Objectives:

Experimentally and theoretically determine spontaneous methane production when hydrate is exposed to CO₂; with the purpose of CO₂ sequestration.

Methane hydrate reservoirs



In-Situ imaging (MRI) of hydrate formation



Methane production by CO₂ injection in field test in Alaska 2012



CCUS Business Opportunities

Key Factors:

- **Energy Strategies & Commercial Revenues**
- **Disruptive New Technologies & Upscaling**
- **Climate Impacts**
- **License to Operate & Public Perception**
- **Government, Industry & Academia Interactions**

Success Criteria for Global CO₂ Storage

- Industry participation
 - Sustainable Economy; Disruptive Technologies at Low Cost
 - CO₂ EOR
 - Verification at Field Scale & at Relevant Location
 - Cost Effective On-Shore Analogues
 - Offshore pilots
 - Whole Value Chain Pilots
 - Whole Value Chain Field Wide CCUS



Planning for an Offshore CO₂ Storage Pilot in the U.S. --- Food for Thought?

Presented By:

Michael Godec, Vice President

Advanced Resources International, Inc.

Arlington, VA USA

Presented at:

US-Norway Collaboration on CCS/CCUS

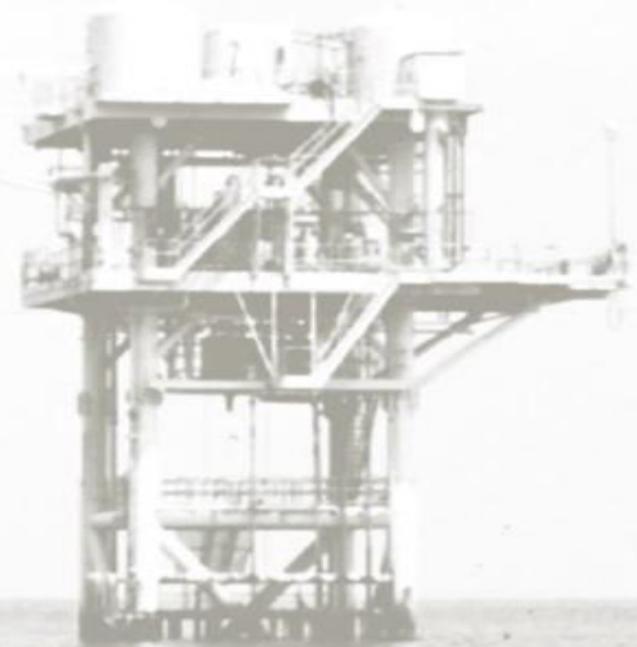
2019 Bilateral Meeting

Pittsburgh, PA

30 August 2019

Differences -- CO₂ Injection Onshore and Offshore

- CO₂ injection and CO₂-EOR offshore will be different from the onshore experience.
- Offshore developments are characterized by fewer wells, larger well spacing, higher rates per well, and a greater degree of heterogeneity between wells.
- The requirement for compression is greater offshore.
- Microscopic sweep efficiency increases due to higher miscibility development.
- Density difference between CO₂ and other fluids decreases; net CO₂ utilization can be higher.
- All this could make offshore reservoirs better candidates for coupled CO₂-EOR and CO₂ storage.



Offshore Storage Challenges

- **High costs**
 - Especially when existing infrastructure cannot be effectively utilized.
 - Hard to “lowball” on costs
 - Leads to need for consortia, collaboration, public-private partnerships, incentives, etc.
- **Common higher permeability offshore can present greater conformance challenges.**
- **Common lower residual oil saturations may reduce potential incremental oil.**
- **Lack of strong industrial imperative – without mandates or significant financial incentives.**
- **Possible non-industrial stakeholder opposition**

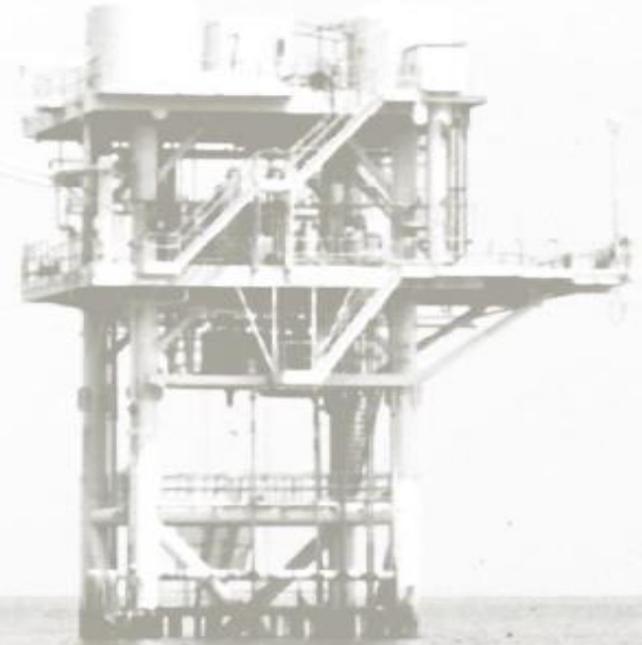


Previous Offshore Gulf of Mexico CO₂-EOR Pilots

Five documented CO₂-EOR pilot projects in the Gulf of Mexico (GOM) in the 1980s.

- Quarantine Bay (Gulf) - miscible CO₂-WAG pilot in small watered-out reservoir; one injector, five producers, and two monitor wells
- Timbalier Bay (Gulf) - gravity-stable, miscible CO₂ flood; one injector, three producers, two monitors
- Bay St. Elaine Field (Texaco) - gravity-stable, miscible CO₂ flood
- Weeks Island Field (Shell) - gravity-stable CO₂ flood in high permeability, steeply dipping reservoir
- Paradis Field (Texaco) - gravity-stable CO₂ flood

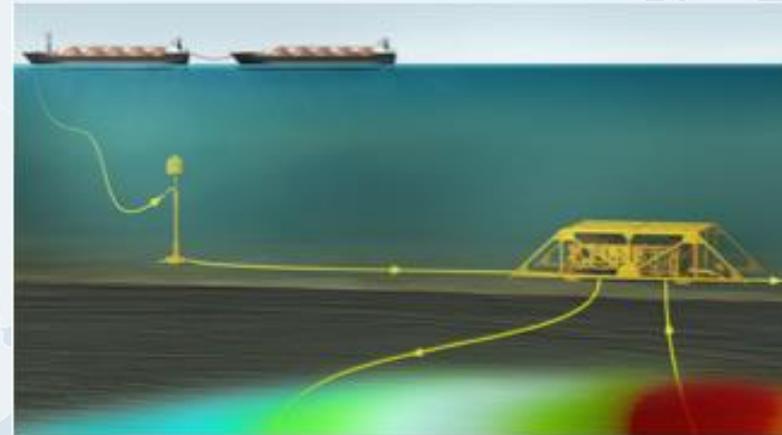
The results from these pilots were mixed.





Purpose of Task Force

- The main purposes of the Task Force were to highlight
 - Main differences between offshore and onshore CO₂-EOR
 - Issues that are different between offshore CO₂-EOR and pure offshore CO₂ storage
 - Technical solutions that will benefit both pure offshore CO₂ storage and offshore CO₂-EOR



Courtesy: AkerSolutions

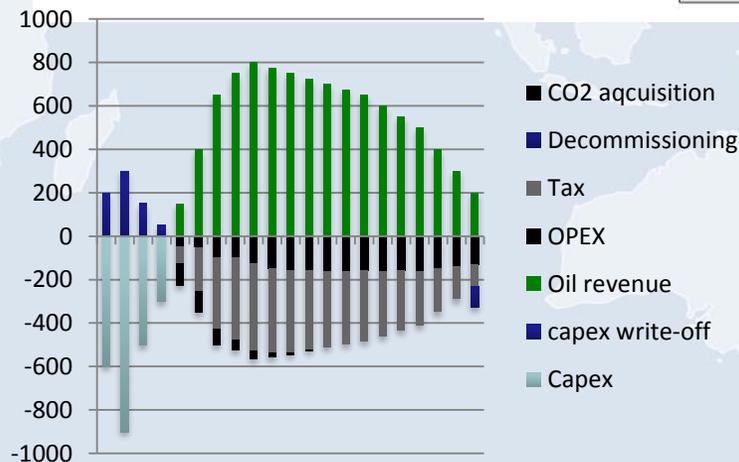
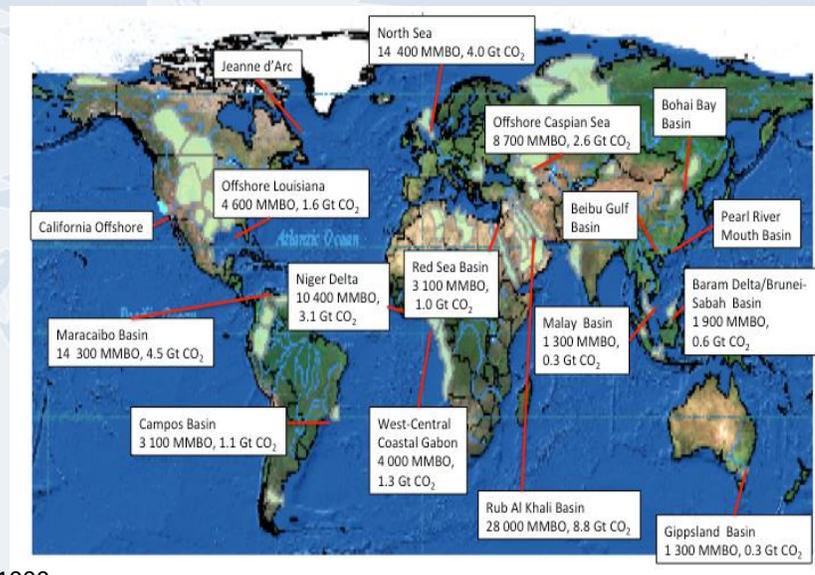
All based on existing, although not necessarily published, information



Potential and economics

- Potential updated with available sources
 - Incremental oil production: 114000 million bbl
 - Stored CO₂: ≈41 GT

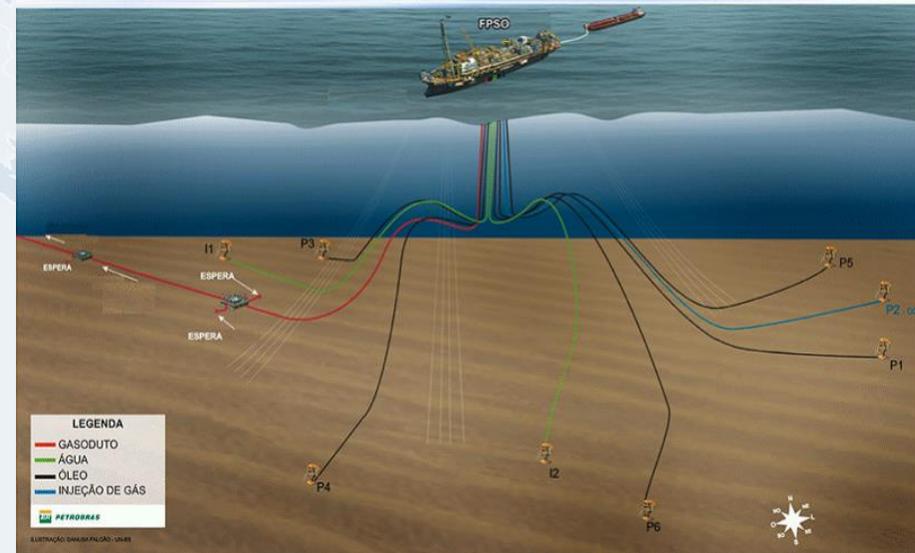
- Economics
 - Discuss some key parameters
 - Cash flow fictitious example





Lula Project

- Reservoir well suited for miscible gas EOR
- CO₂ content in gas ≈ 11 %
- Extensive reservoir characterization
- Robust and flexible development strategy
- Careful choice of topside solution and materials
- Membranes used for CO₂ separation
- WAG solution with six producers, two WAG injectors, one CO₂ injector
- No major operational or reservoir problems
- Monitoring with downhole pressure gauges and tracers





Approaches for enabling offshore CO₂-EOR

- Using late-life oilfield infrastructure
- Using oilfield satellite projects
- Focusing CO-EOR on the residual oil zone (ROZ)
- Reservoir modelling: Issues particular to CO₂-EOR
 - Phase behaviour
 - Reactions with rocks
 - Multiphase flow in porous media
 - Oil instability

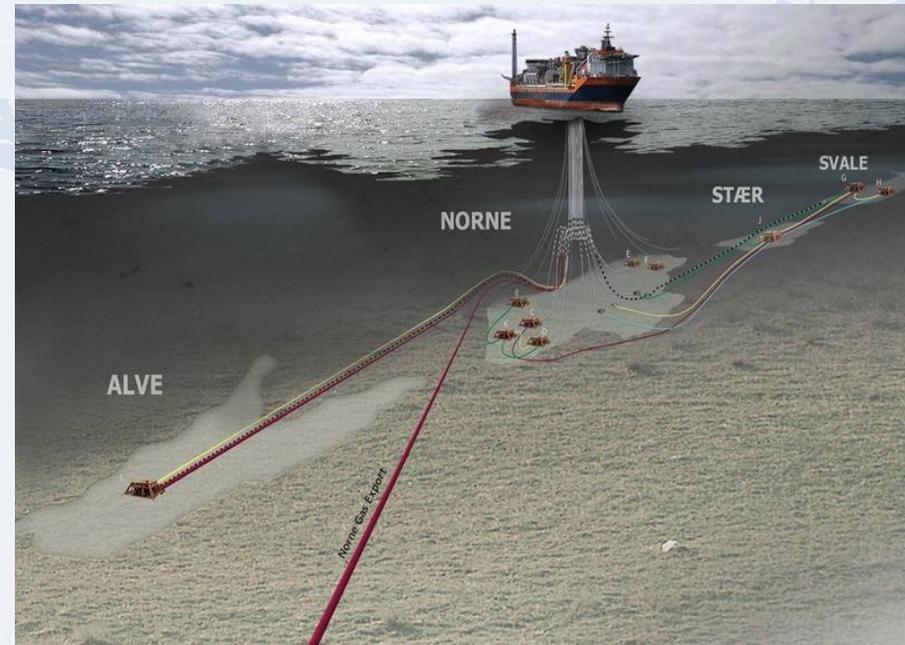
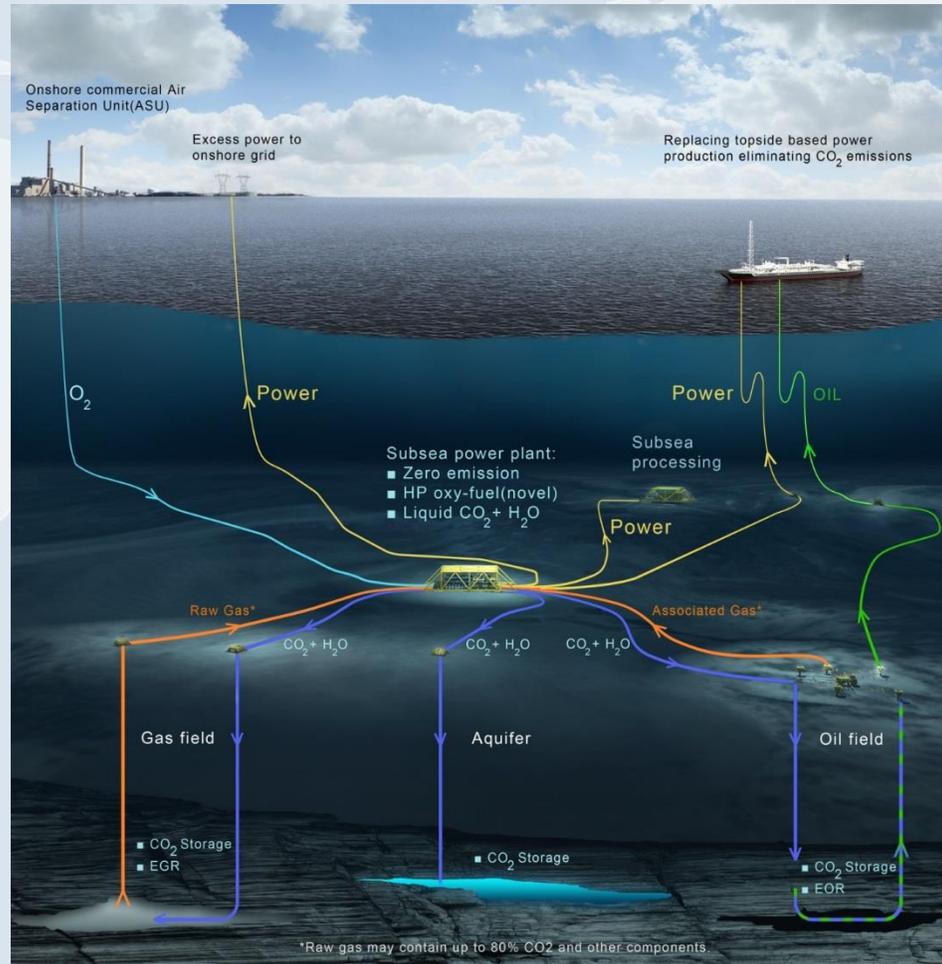




Illustration of subsea zero emission offshore power generation and CO₂ separation concept



(Courtesy Aker Solutions)



Mobility control (next generation EOR technology)

- CO₂ mobility control important offshore due to large well spacing
- Use increased miscibility oil and CO₂
- CO₂ foam a potential remedy for fingering etc that reduce volumetric sweep and effectiveness of injection
- Will increase oil recovery as well as CO₂ storage
- International cooperation needed
- Up-scaling from laboratory to onshore and offshore pertains major issue

WHY TEXAS?

- CO₂ is commercially available
- Foam as mobility control
- Up-scaling; major challenge in oil recovery
- Fraction of costs of off-shore field tests
- Fast results: short inter-well distances
- 30 years experience in Texas on CO₂ EOR
- 4D seismic establishes a field laboratory



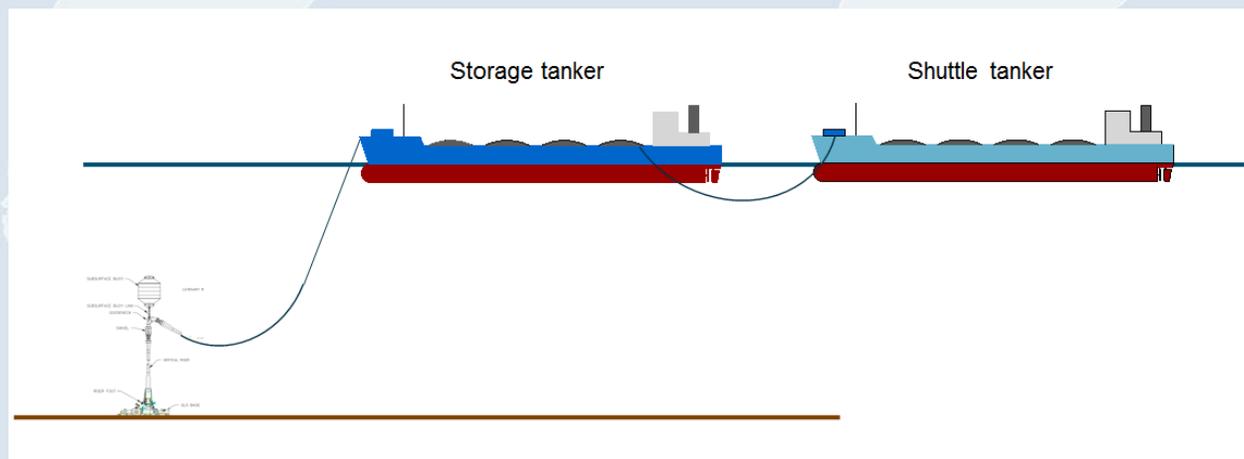
Conclusions emerging technologies

- Significant and promising technologies for reducing the cost of separating CO₂ from production fluids in CO₂-EOR operations are under development and, to some degree, testing.
- Compact sub-sea equipment for CO₂ processing and mobility control using CO₂ foam appear to have large potential when it comes to reducing CAPEX and OPEX for CO₂-EOR projects.

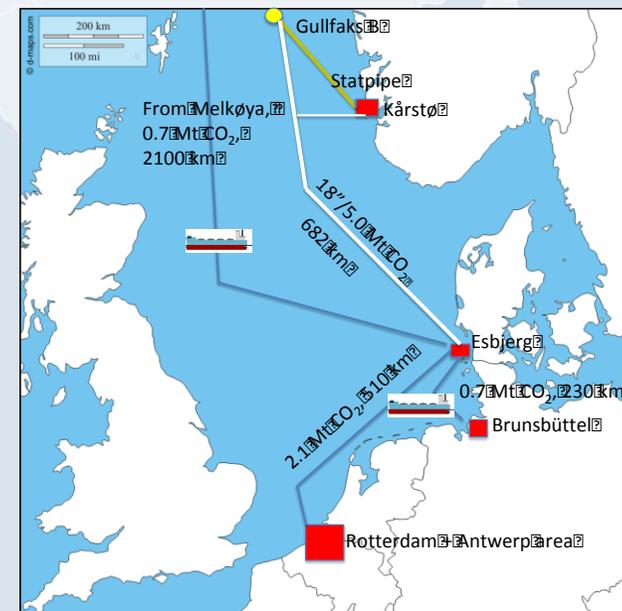


CO₂ supply chain issues

- No technical barriers to CO₂ infrastructure for offshore EOR
- Optimisation will bring costs down
- Some system parts need qualification
- Barriers are commercial and political in nature



Bow to stern loading from shuttle tanker to storage and injection vessel.
Possible buoy solution indicated. (Courtesy Aker Solutions)



A network of sources and transportation means to supply Gullfaks with 5.5 MT CO₂/year. Based on Agustsson and Grinestad (2005), Berger et al. (2004) and Elsam et al., 2003



MVA

- Offshore CO₂-EOR is much less mature than onshore CO₂-EOR and offshore dedicated CO₂ storage
- Will have different risk profiles that require special considerations when designing an MVA programme for offshore CO₂-EOR.
- A range of monitoring technologies applied in the two other settings are applicable also to offshore CO₂-EOR.
- The review did not identify any technical barriers for proper monitoring of offshore CO₂-EOR fields



Regulatory requirements

- In all regions considered here, it appears that CO₂ EOR activities can be regulated under existing oil and gas regulation
- However, to demonstrate long-term storage, or seeking incentives (such as carbon credits), the same challenges as transitioning from CO₂-EOR to CO₂ storage onshore are met
- In general, transitional requirements do not exist



Summary

Use of CO₂ as a commodity:

Business Case for CO₂ Storage:

- CO₂ EOR
- Integrated EOR (IEOR) with Foam: *Carbon Negative Oil Production*
- Exploitation of Hydrate Energy: *Carbon Neutral Gas Production*

Way Forward

New technologies ready for industrial scale implementation:

- Onshore in Permian Basin, USA (80% CO₂EOR, EOR target 137Bbbl)
- Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil
- International Whole Value Chain CCUS Collaboration Offshore